NACA

RESEARCH MEMORANDUM

INVESTIGATION OF THE EFFECT OF BALANCING TABS ON THE HINGE-MOMENT CHARACTERISTICS OF A TRAILING-EDGE FLAP-TYPE CONTROL ON A TRAPEZOIDAL WING AT A MACH NUMBER OF 1.61

By Douglas R. Lord and Cornelius Driver

Langley Aeronautical Laboratory
Langley Field, Va.

[redacted]

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
August 5, 1954

[redacted]

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

INVESTIGATION OF THE EFFECT OF BALANCING TABS ON THE HINGE-MOMENT CHARACTERISTICS OF A TRAILING-EDGE FLAP-TYPE CONTROL ON A TRAPEZOIDAL WING AT A MACH NUMBER OF 1.61

By Douglas R. Lord and Cornelius Driver

SUMMARY

An investigation has been made at a Mach number of 1.61 for a Reynolds number of 3.6×10^6 to determine the effect of 10-percent control area attached tabs on the hinge-moment characteristics of a trailing-edge flap-type control on a trapezoidal wing having a 23° sweptback leading edge, aspect ratio of 3.1, and taper ratio of 0.4. Control hinge moments were measured over a control deflection range from -30° to 30° at angles of attack from -12° to 12° with tab deflections of approximately 0°, -10°, and -20°.

Theoretical calculations based on linear theory considerably overestimated the incremental hinge moments due to the tabs, but underestimated the large ratios of tab to control deflection required to balance the hinge moments due to control deflection. The configuration having a geared tab located inboard on the sweptforward control trailing edge was more effective in balancing the control hinge moments and maintained considerably more control effectiveness than the configuration having an equal-area tab located outboard.

INTRODUCTION

As part of a general program of research on controls, an investigation is under way in the Langley 4- by 4-foot supersonic pressure tunnel to determine the important parameters in the design of controls for use on various types of wings at supersonic speeds. Tests have been made on a trapezoidal wing of aspect ratio 3.1, taper ratio of 0.4, and having 23° of sweep of the leading edge. Control effectiveness and hinge-moment results for the wing equipped with various partial and full-span trailing-edge flap-type controls were reported in reference 1. In an attempt to reduce the hinge moments of the full-span control of reference 1, attached tabs were tested at the inboard and outboard ends of the control trailing edge. The results of these tests are presented in this paper. The results of some preliminary tests of tabs designed to reduce the hinge moments of unbalanced controls at supersonic speeds were reported in references 2 and 3.

The present tests were made at wing angles of attack from -12° to 12° for control deflections from -30° to 30° and for tab deflections of approximately 0°, -10°, and -20°. The free-stream Mach number of the tests was 1.61 and the Reynolds number, based on the wing mean aerodynamic chord, was 3.6×10^{6}.

SYMBOLS

M stream Mach number

q stream dynamic pressure

α wing angle of attack

δ control deflection relative to wing chord plane, perpendicular to the control hinge line, positive when control trailing edge is down

δ_T tab deflection relative to control chord plane, perpendicular to the control trailing edge, positive when tab trailing edge is down

S control plan-form area (excluding tab)

$\bar{c}$ control mean aerodynamic chord (excluding tab)

M_{HL} tab-area moment about control hinge line

H control hinge moment about hinge line

C_h control hinge-moment coefficient, $H/qS\bar{c}$

ΔC_h increment in control hinge-moment coefficient due to presence of tab

Slope parameters:

$$C_{h_\delta} = \frac{\partial C_h}{\partial \delta}$$

$$C_{h_{\delta_T}} = \frac{\partial C_h}{\partial \delta_T}$$

$$\frac{\delta_T}{\delta} = -\frac{C_{h_\delta}}{C_{h_{\delta_T}}}$$

$$\Delta C_{h_\alpha} = \frac{\partial \Delta C_h}{\partial \alpha}$$

$$\Delta C_{h_\delta} = \frac{\partial \Delta C_h}{\partial \delta}$$

$$\Delta C_{h_{\delta_T}} = \frac{\partial \Delta C_h}{\partial \delta_T} = C_{h_{\delta_T}}$$

All slopes were obtained at $\alpha = 0^\circ$, $\delta = 0^\circ$, $\delta_T = 0^\circ$.

APPARATUS

Wind Tunnel

This investigation was conducted in the Langley 4- by 4-foot supersonic pressure tunnel, which is a rectangular, closed-throat, single-return type wind tunnel with provisions for the control of the pressure, temperature, and humidity of the enclosed air. Flexible nozzle walls were adjusted to give the desired test-section Mach number of 1.61. During the tests, the dewpoint was kept below -20° F so that the effects of water condensation in the supersonic nozzle were negligible.

Model and Model Mounting

The model used in this investigation consisted of a trapezoidal wing having a full-span trailing-edge flap-type control (configuration 4 of ref. 1). The control plan-form area was 25 percent of the wing area. A tab having an area 10 percent of the control area and a span 25 percent of the control span was attached at the control trailing edge, first at the inboard location and then at the outboard location as shown in figure 1.

The basic wing had a 23° sweptback leading edge, a root chord of 15.88 inches, a tip chord of 6.17 inches, and a semispan of 17.02 inches. The wing section was a modified hexagon having a ratio of thickness to chord of 4.5 percent based on the local chord. The flat midsection (fig. 1) extended from 30 percent chord to 70 percent chord and the intersections of the flat midsection to the leading- and trailing-edge wedges were rounded. The control hinge line was unswept and was located at the 74.6-percent-chord station.

The wing and control were constructed of steel and the tab was constructed of 1/16-inch stock brass. All screw holes, pits, and mating lines were filled with dental plaster and faired smooth. The semispan wing was mounted horizontally in the tunnel from a turntable in a steel boundary-layer bypass plate which was located vertically in the test section about 10 inches from the side wall as shown in figure 2.

TESTS

The model angle of attack was changed by rotating the turntable in the bypass plate on which the wing was mounted (see fig. 2). The angle of attack was measured by a vernier on the outside of the tunnel, inasmuch as the angular deflection of the wing under load was negligible. Control deflection was changed by a gear mechanism mounted on the pressure box which rotated the strain-gage balance, the torque tube, and the control as a unit. The control deflections were set with the aid of an electrical control-position indicator mounted inside the wing at the hinge line and were checked with a cathetometer mounted outside the tunnel. Control hinge moments were determined by means of an electrical strain-gage balance located in the pressure box (fig. 2) which measured the torque on the tube actuating the control.

The tests were made for nominal tab deflections of 0°, -10°, and -20° at angles of attack of 0°, ±6°, ±12°. Hinge-moment measurements were made at 5° increments over the control-deflection range from -30° to 30°. The tests were made at a tunnel stagnation pressure of 13.0 pounds per square inch absolute at a Mach number of 1.61, corresponding to a Reynolds number based on the wing mean aerodynamic chord of 3.6×10^6. Throughout the tests a 3/16-inch strip of no. 60 carborundum spanned the model 1/4 inch from the leading edge, to insure a turbulent boundary layer over the model.

PRECISION OF DATA

The mean Mach number in the region occupied by the model is estimated from calibration data to be 1.61 with local variations being smaller than ±0.02. There is no evidence of any significant flow angularities. The estimated accuracy of other pertinent quantities is:

α, deg	±0.05
δ, deg	±0.1
δ_T, deg	±0.1
C_h	±0.01

THEORETICAL CALCULATIONS

The theoretical calculations of the incremental hinge-moment coefficient slopes $\Delta C_{h_{\delta_T}}$, ΔC_{h_δ}, and ΔC_{h_α} were computed on the basis of linear theory, after making the simplifying assumption that the tab tips were streamwise, rather than normal to the control trailing edge as tested. The method followed was the same as that used in reference 4, in that the two-dimensional regions and the triangular segments of the conical-flow regions, caused by deflections of the tab, the control, or the wing, were considered independently. The average pressure ratios and center-of-pressure ray locations for the conical-flow regions were determined from references 4 and 5. For computing the loadings due to control deflection and angle of attack in the conical-flow regions at the outboard tip of the inboard tab and at the inboard tip of the outboard tab, it was assumed that the loadings were the same as those used in computing the loadings due to tab deflection for the isolated tab. After determining the loadings on the conical-flow regions and on the two-dimensional regions for each particular case, the contribution to the control hinge moment of the portion of the loading that was on the tab could be obtained.

RESULTS AND DISCUSSION

Hinge-Moment Coefficients

The variations of control hinge-moment coefficient with control deflection for the basic control without a tab and for the six tab configurations are presented in figure 3. In general the curves are approximately linear, except near the largest control deflections, where the slopes tend to decrease. This occurs for both the basic and tab configurations and is in general agreement with the pitching-moment results of reference 1, which showed a decreased pitching-moment effectiveness for the large control deflections. This decrease was attributed to flow separation ahead of the high-pressure side of the control causing a forward shift in the center of pressure and a reduced loading on the control. The addition of the tab to the basic configuration at either location causes increased slopes of the curves of control hinge-moment coefficient with control deflection (fig. 3) as would be expected. Changing the tab deflection from approximately 0° to -20° caused little change in slopes, as predicted by linear theory, and as was shown in the tip control-tab tests of reference 2.

Cross plots of the curves of figure 3 are shown in figure 4, where the variations of control hinge-moment coefficient with tab deflection are plotted for the inboard and outboard tab locations at $\alpha = 0^{\circ}$. The curves at the other angles of attack are very similar and are therefore omitted. The positive tab deflection values for this analysis were obtained by assuming symmetry of the data for opposite angle conditions. The curves of figure 4 are linear and parallel over most of the range, except for the largest control deflections and tab deflections, where the tab effectiveness is reduced.

Tab Parameters

Both the inboard and outboard tabs are the same size; however, due to the taper of the control, moving the tab from the inboard to the outboard position reduces the moment arm of the tab about the control hinge line, and therefore, reduces the effectiveness of the tab as a balancing device. The theoretical and experimental incremental hinge-moment coefficient slopes have been plotted in figure 5 as functions of tab-area moment about the control hinge line. The variations of $\Delta C_{h_{\delta_T}}$ with M_{HL} are approximately linear, indicating that the moment about the tab leading edge of the lift due to tab deflection is unaffected by spanwise movement of the tab. The variations of $\Delta C_{h_{\delta}}$ and $\Delta C_{h_{\alpha}}$ with M_{HL} are not linear because of the relatively large losses of lift near the wing tip due to control deflection and angle of attack. In the case of $\Delta C_{h_{\delta}}$, there is no corresponding loss on the inboard tab since the hinge line is unswept and the bypass plate acts as a reflection plane. In the case of C_{h_α}, there is some loss on the inboard tab due to the conical-flow region from the wing apex; however, this loss is indicated by theory to be small in relation to the loss in the tip region.

The theoretical curves of figure 5 show the proper trends of the variations with tab-area moment, but considerably overestimate the effectiveness of the tabs on each of the parameters. It appears that the thickness and viscous effects near the wing trailing edge which are evident in the unpublished pressure distributions make it impossible to predict with any degree of accuracy (by the linear theory method) the characteristics of attached tabs. The tests of reference 2 showed similar results.

The theoretical and experimental ratios of tab deflection to control deflection required for $C_{h_\delta} = 0$ are plotted in figure 6 as functions of angle of attack for the two tab locations tested. Within the range of angles of attack tested there seems to be little change in the experimental values obtained; however, the experimental ratios of -6 and -8 are large when compared to normal subsonic and transonic values. The tests of reference 6 showed values of δ_T/δ near -3 for a 15-percent area attached tab at $M = 1.0$ and values near -2 for subsonic conditions.

The theoretical curves of figure 6 show that the theory considerably underestimates the tab-control deflection ratios for balanced hinge-moment curves. This at first seems contradictory when considering the approximately equal percentage differences between the experimental and theoretical values of $\Delta C_{h_{\delta_T}}$ and ΔC_{h_δ} shown in figure 5. In reference 1 it was shown that the linear theory predicted approximately 76 percent of the experimental C_{h_δ} value for the basic control without tab.

Since

$$\frac{\delta_T}{\delta} = - \frac{C_{h_\delta}(\text{with tab})}{C_{h_{\delta_T}}} = - \frac{C_{h_\delta}(\text{no tab}) + \Delta C_{h_\delta}}{\Delta C_{h_{\delta_T}}}$$

and the absolute value of C_{h_δ}(no tab) is considerably greater than that of ΔC_{h_δ}, the numerator of the equation is predicted much better than is the denominator. The net result is that the overestimation of $\Delta C_{h_{\delta_T}}$ by the theory is of greater significance and results in a much smaller value of δ_T/δ than is obtained experimentally.

The smaller experimental value of δ_T/δ for the inboard tab than for the outboard tab is predicted by the theory and would be expected from the tab-area moment relation. On an equal tab-area moment basis, such as would exist for equal size tabs on an unswept trailing edge, the outboard location would probably be more effective in reducing the control hinge moments due to control deflection, since $\Delta C_{h_{\delta_T}}$ would be the same at either location and ΔC_{h_δ} would be smaller for the outboard location due to the loss in lift in the tip region of the control.

Control Effectiveness

In the present investigation it was impossible to measure directly the control effectiveness as affected by the balancing tabs. In order to complete the analysis of the balanced hinge-moment condition $\left(C_{h_\delta} = 0\right)$, it would be desirable to know the control effectiveness of the complete configuration. Inspection of unpublished pressure distributions made on the control ahead of the tabs indicated that for the range of tab angles investigated herein there was little if any influence on the pressures ahead of the tabs so long as they were deflected in opposition to the control deflection. Since the increment in hinge moment from the no tab to the tab condition could be assumed to be entirely due to the load on the tab, it was possible by further assuming a uniform tab load distribution, to determine the lift on the tab and therefore on the complete tab-control configuration.

This analysis showed that for the tabs investigated, the inboard tab configuration was the most successful in maintaining the control effectiveness of the basic unbalanced control configuration, while balancing the control hinge moments due to control deflection. The inboard tab-control combination geared for $C_{h_\delta} = 0$ suffered approximately a one-third reduction in lift effectiveness, a one-tenth reduction in root bending-moment effectiveness (indicative of rolling-moment loss), and a one-half reduction in pitching-moment effectiveness about the midchord of the wing mean aerodynamic chord. In contrast, the outboard tab-control combination geared for $C_{h_\delta} = 0$ lost approximately one-half the lift effectiveness, gave reversed bending-moment effectiveness, and lost about two-thirds the pitching-moment effectiveness. From the overall viewpoint, it, therefore, appears that the inboard location of the tab is the most advantageous.

CONCLUDING REMARKS

An investigation has been made at a Mach number of 1.61 to determine the effect of 10-percent control-area attached tabs on the hinge-moment characteristics of a trailing-edge control on a trapezoidal wing. Theoretical calculations based on linear theory considerably overestimated the effect of tab deflection on the control hinge moments and the effect of the undeflected tab on the hinge-moment coefficient slopes with control deflection and angle of attack.

The experimental ratios of tab deflection to control deflection required to balance the hinge moments due to control deflection were large and were underestimated by the theoretical predictions. The configuration having a geared tab located at the inboard end of the swept-forward control trailing edge was more effective in balancing the control hinge moments and maintained considerably more control effectiveness than the configuration having an equal-area tab located at the outboard end of the control trailing edge.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 9, 1954.

REFERENCES

1. Lord, Douglas R., and Czarnecki, K. R.: Aerodynamic Characteristics of Several Flap-Type Trailing-Edge Controls on a Trapezoidal Wing at Mach Numbers of 1.61 and 2.01. NACA RM L54D19, 1954.

2. Czarnecki, K. R. and Lord, Douglas R.: Preliminary Investigation of the Effect of Fences and Balancing Tabs on the Hinge-Moment Characteristics of a Tip Control on a 60° Delta Wing at Mach Number 1.61. NACA RM L53D14, 1953.

3. Boyd, John W., and Pfyl, Frank A.: Experimental Investigation of Aerodynamically Balanced Trailing-Edge Control Surfaces on an Aspect Ratio 2 Triangular Wing at Subsonic and Supersonic Speeds. NACA RM A52L04, 1953.

4. Goin, Kennith L.: Equations and Charts for the Rapid Estimation of Hinge-Moment and Effectiveness Parameters for Trailing-Edge Controls Having Leading and Trailing Edges Swept Ahead of the Mach Lines. NACA Rep. 1041, 1951. (Supersedes NACA TN 2221.)

5. Harmon, Sidney M., and Jeffreys, Isabella: Theoretical Lift and Damping in Roll of Thin Wings With Arbitrary Sweep and Taper at Supersonic Speeds - Supersonic Leading and Trailing Edges. NACA TN 2114, 1950.

6. Lockwood, Vernard E., and Fikes, Joseph E.: Preliminary Investigation at Transonic Speeds of the Effect of Balancing Tabs on the Hinge-Moment and Other Aerodynamic Characteristics of a Full-Span Flap on a Tapered 45° Sweptback Wing of Aspect Ratio 3. NACA RM L52A23, 1952.

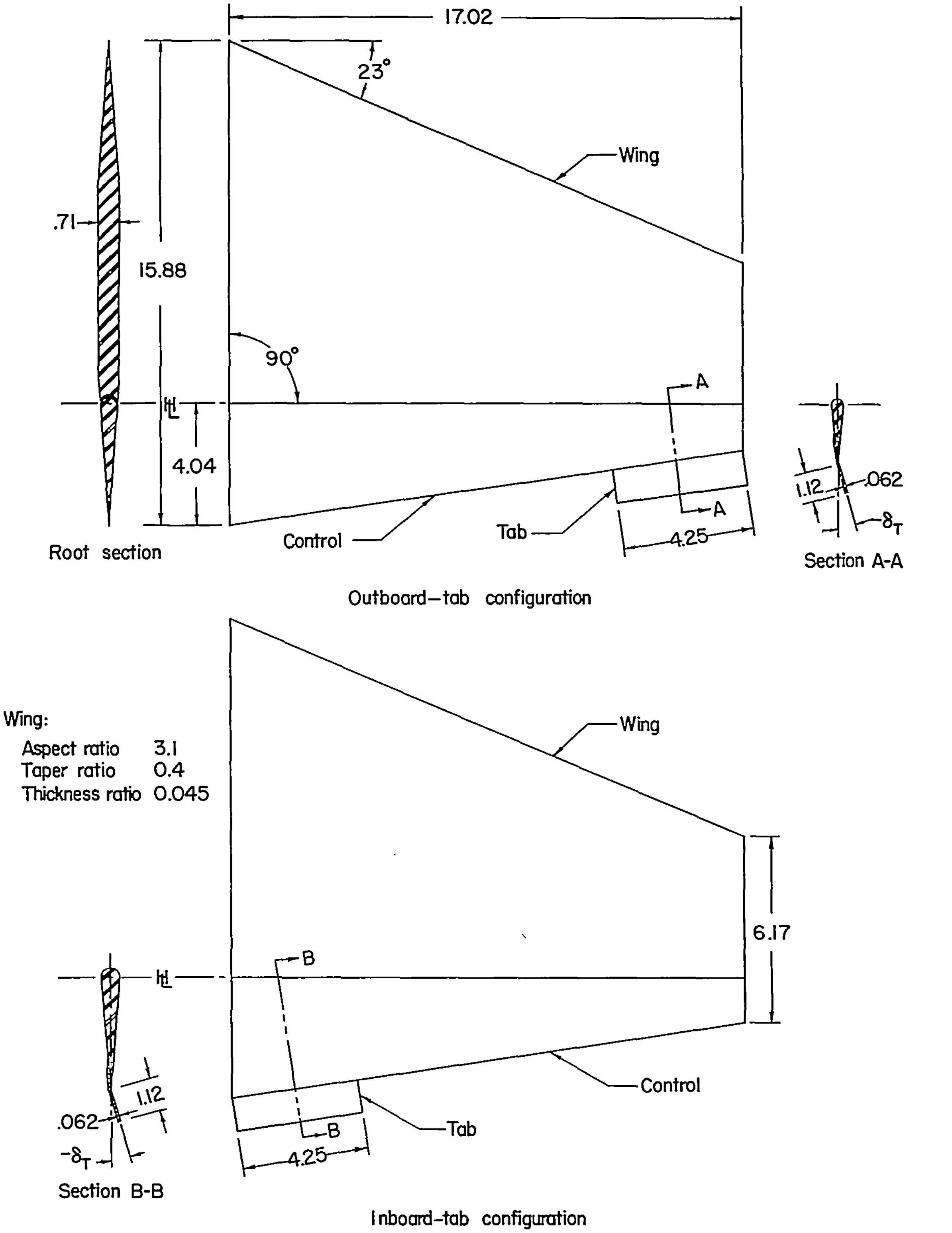
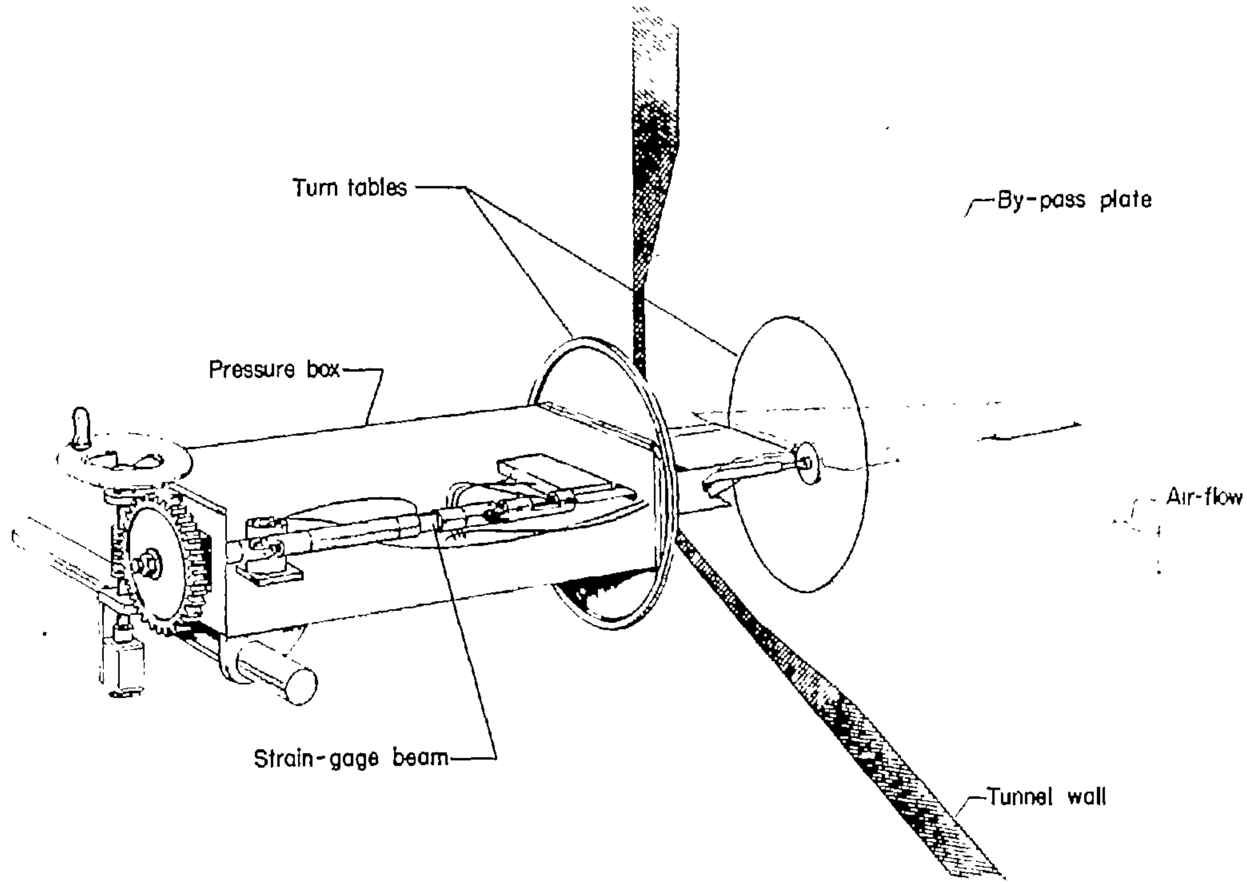
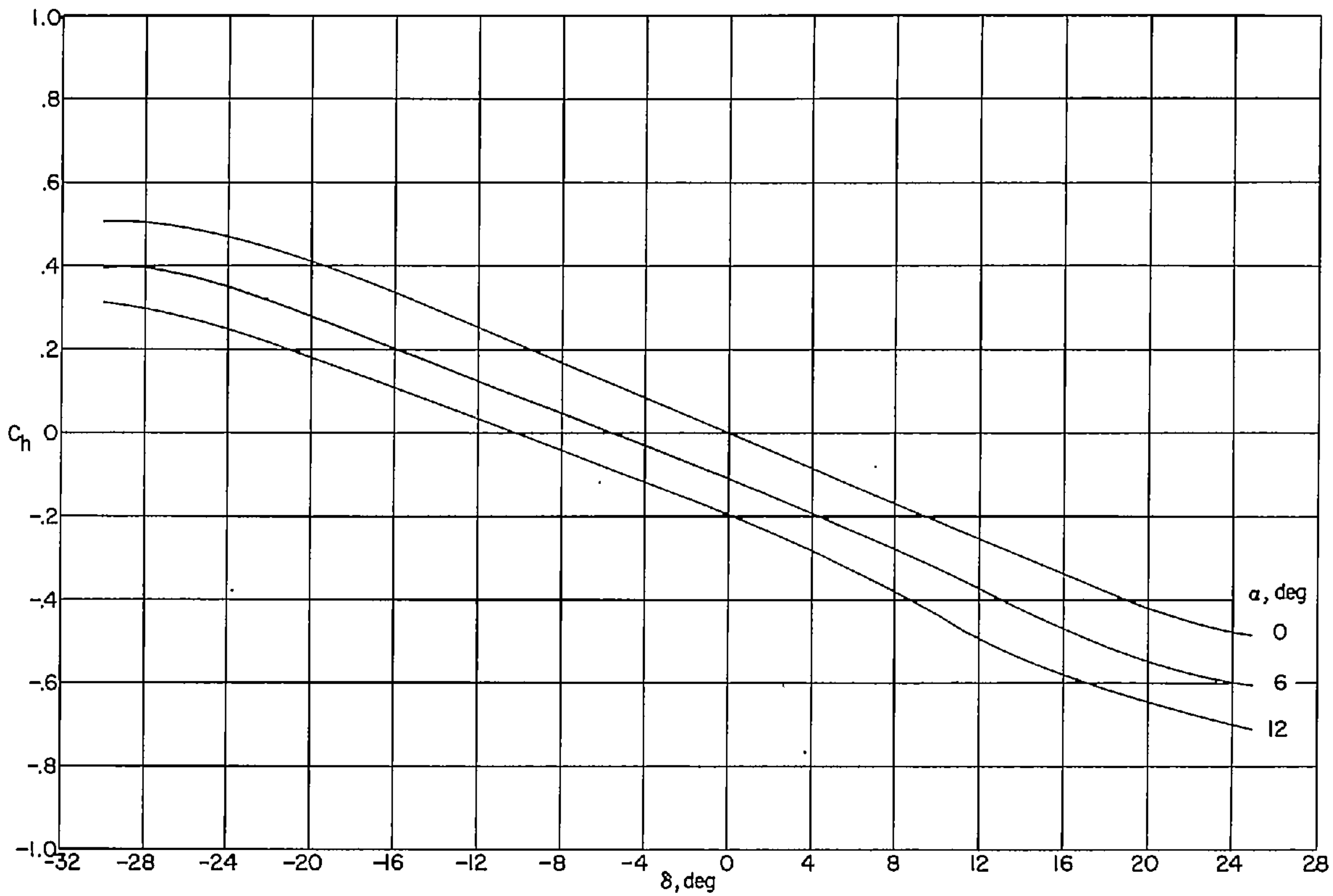


Figure 1.- Sketch of model configurations. All dimensions are in inches.



L-83645

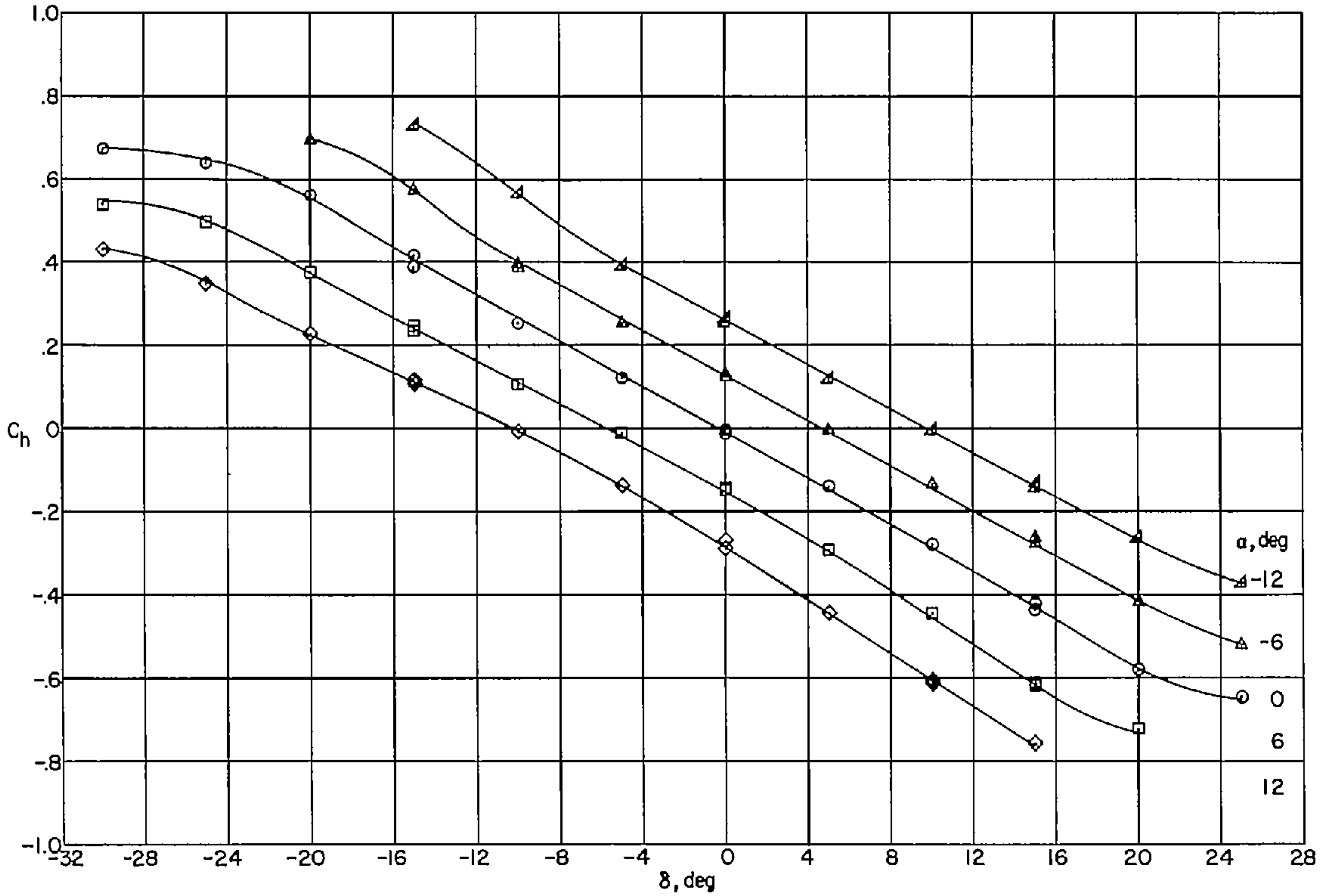
Figure 2.- Sketch of typical test setup.



(a) Basic control (from ref. 1).

Figure 3.- Variation of control hinge-moment coefficient with control deflection.

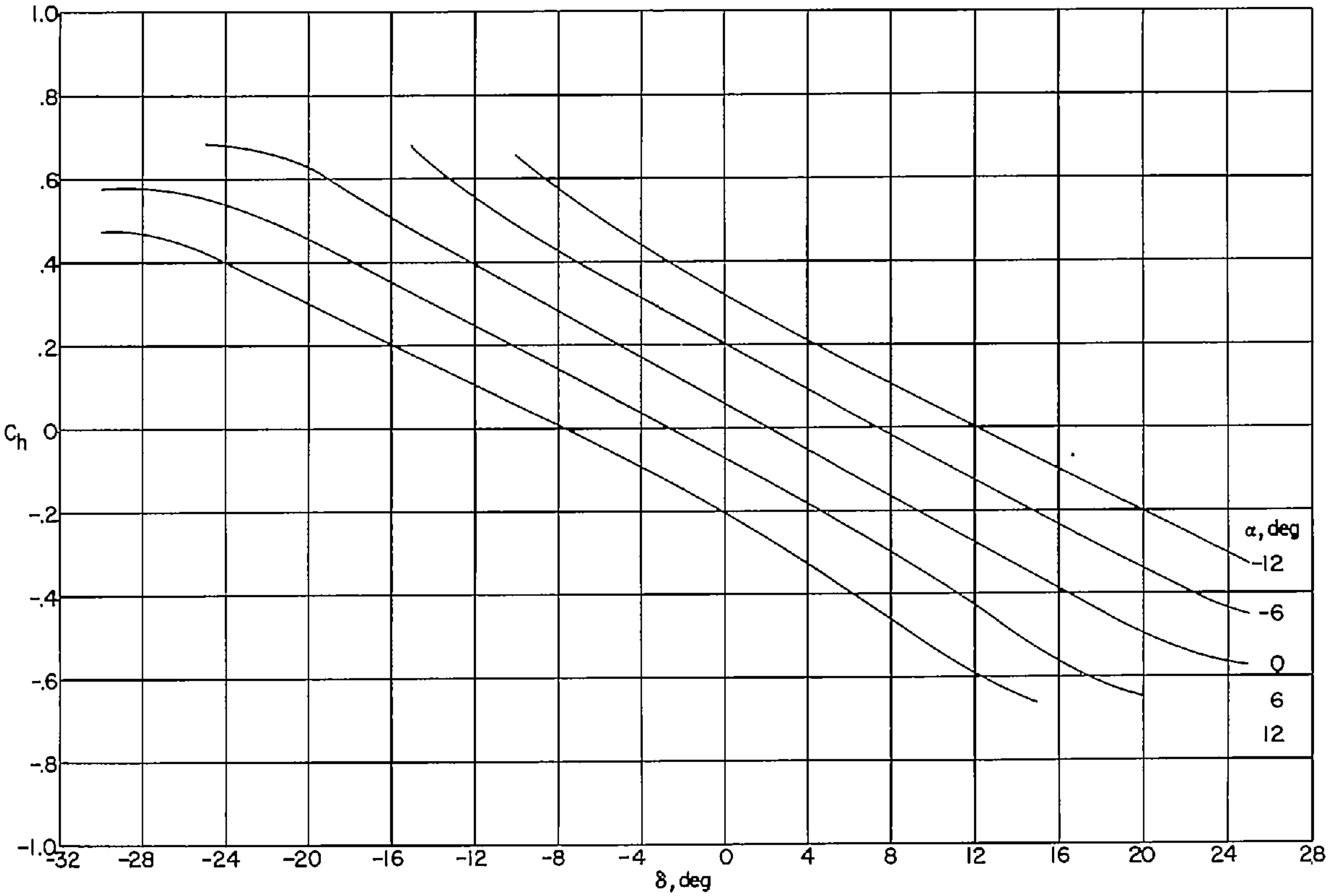
[redacted]



(b) Inboard tab; $\delta_T = 1.0^\circ$. Test symbols shown on this figure to illustrate accuracy of fairings.

Figure 3.- Continued.

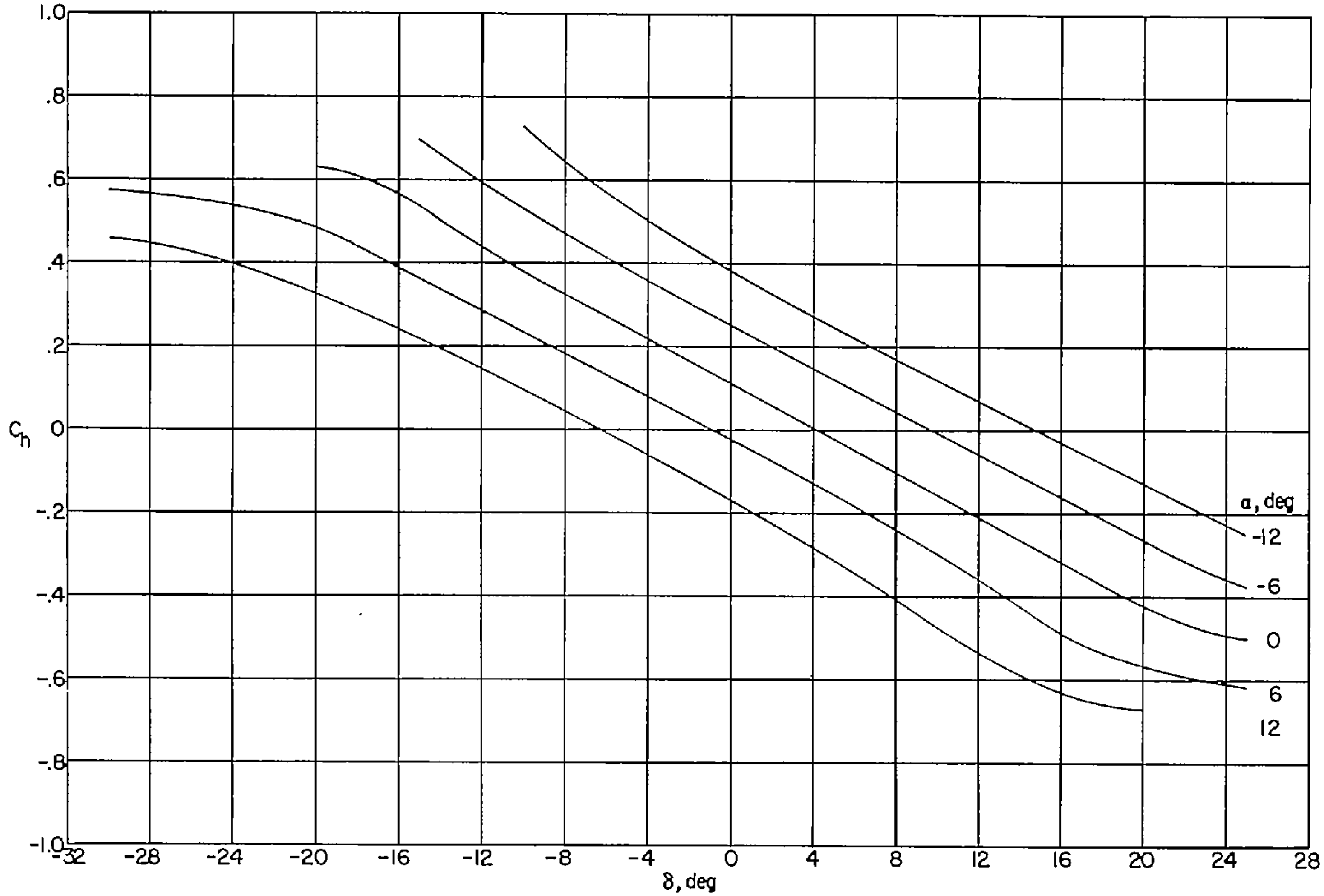
[redacted]



(c) Inboard tab; $\delta_T = -9.7^{\circ}$.

Figure 3.- Continued.

[redacted]

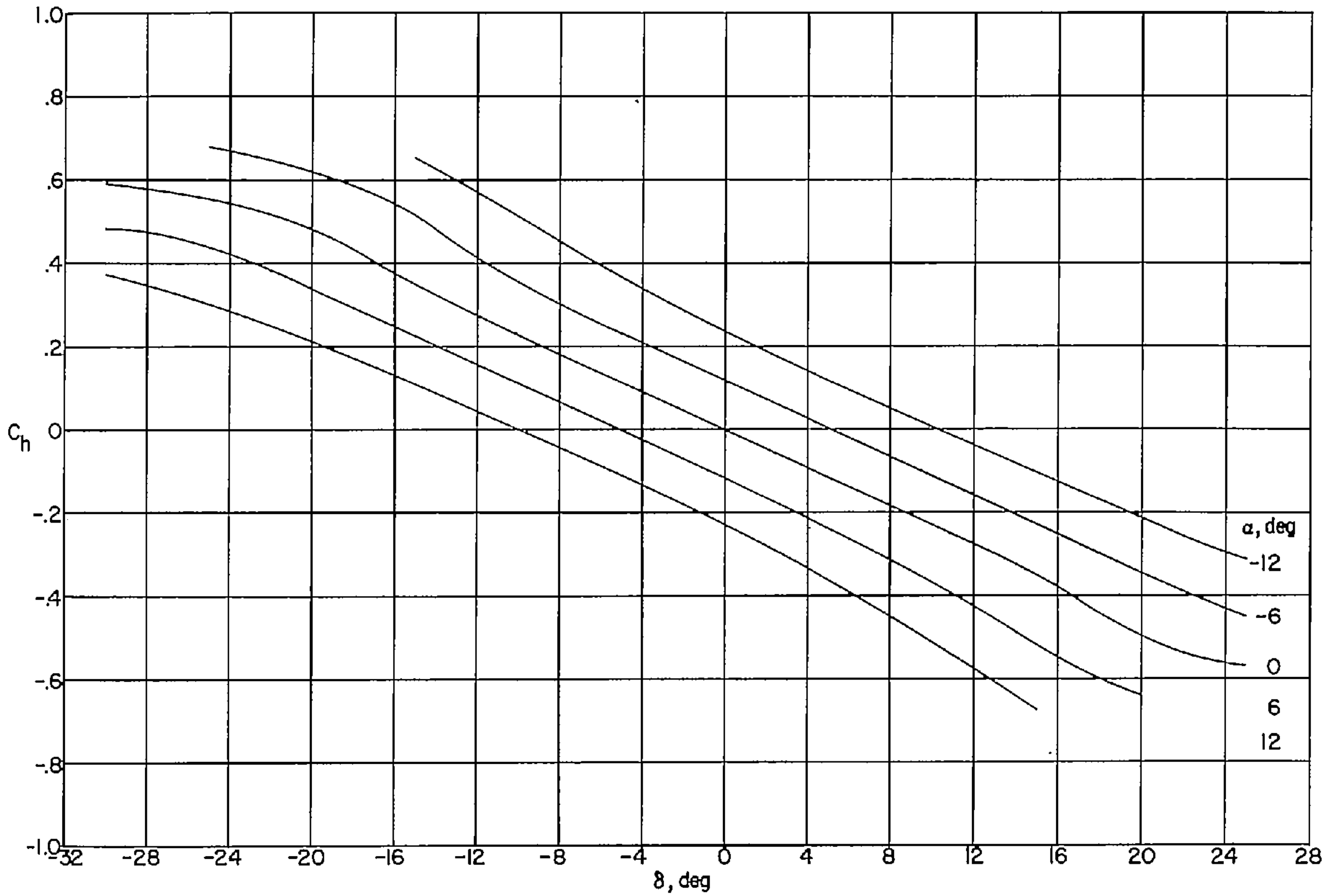


(d) Inboard tab; $\delta_T = -24.2^\circ$.

Figure 3.- Continued.

[redacted]

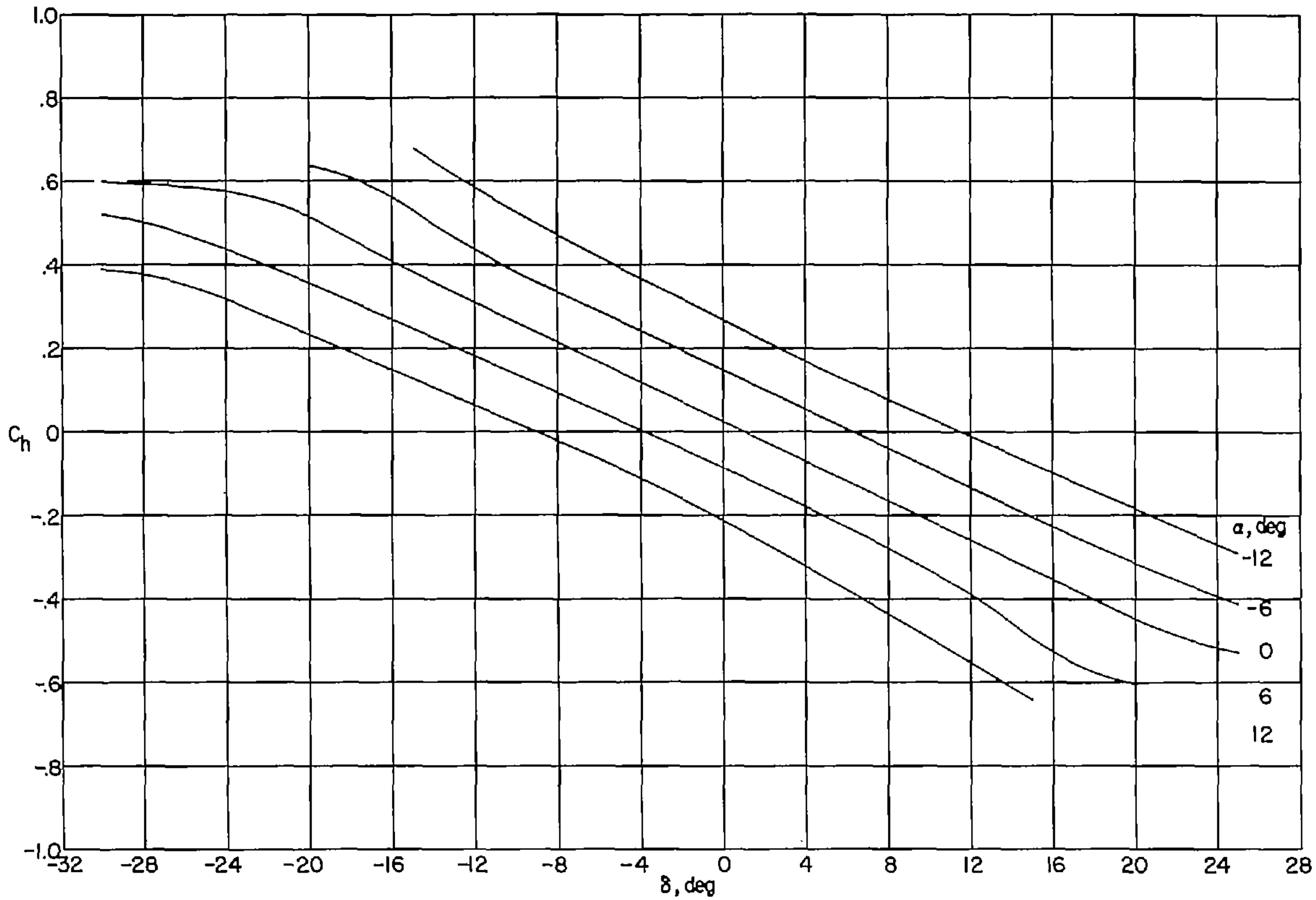
[redacted]



(e) Outboard tab; $\delta_T = 0^{\circ}$.

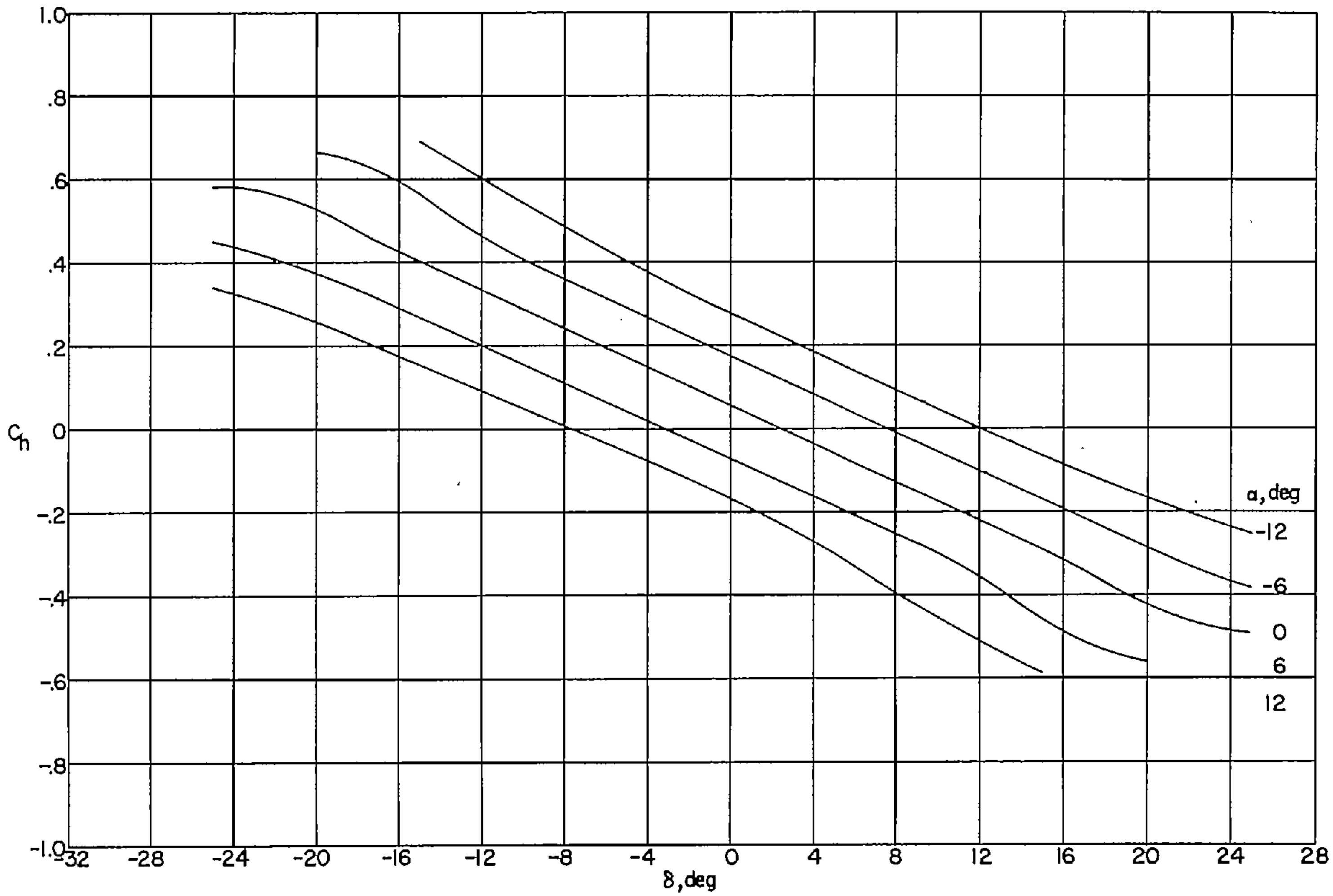
Figure 3.- Continued.

[redacted]



(f) Outboard tab; $\delta_T = -8.5^{\circ}$.

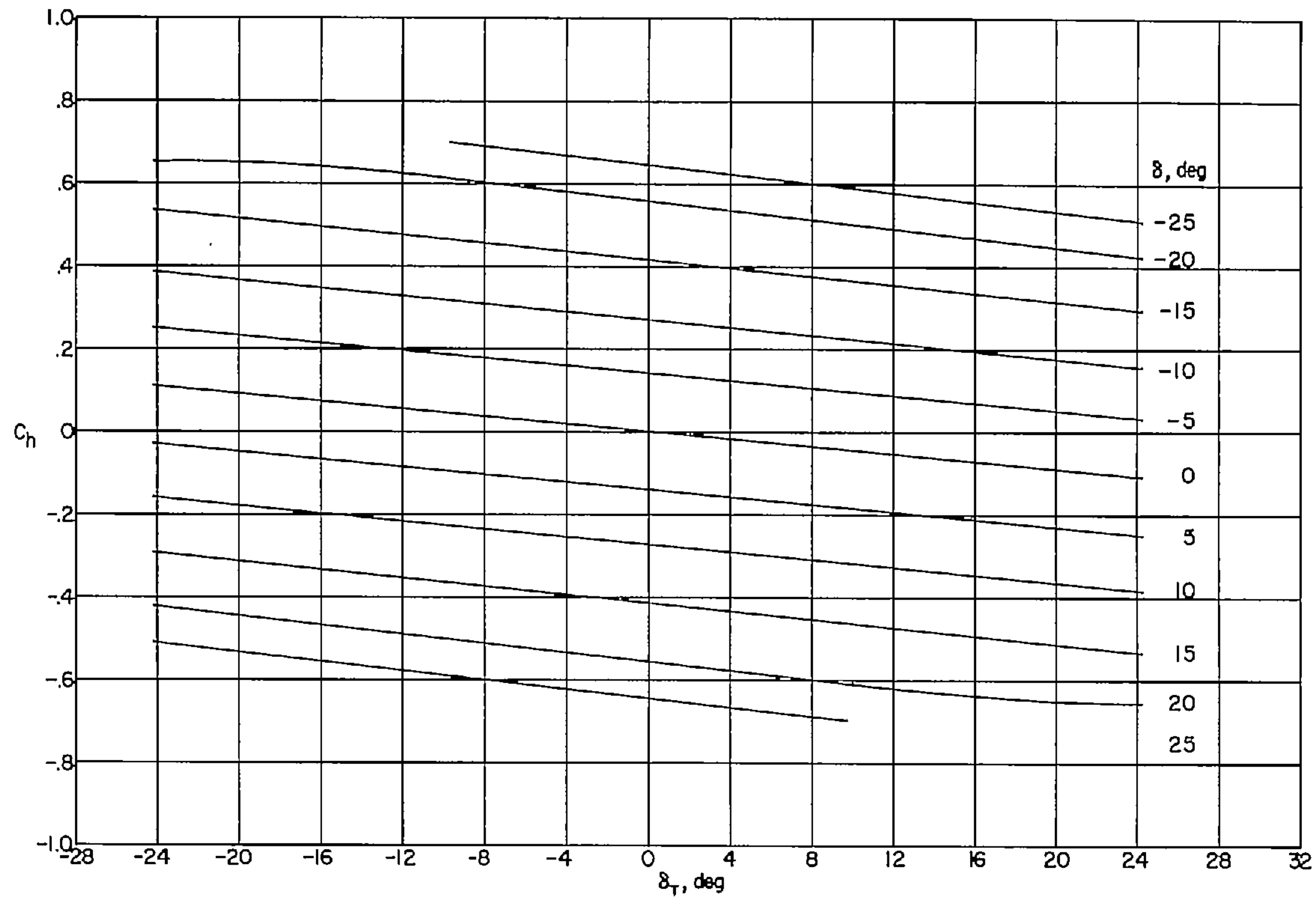
Figure 3.- Continued.



(g) Outboard tab; $\delta_T = -20.0^{\circ}$.

Figure 3.- Concluded.

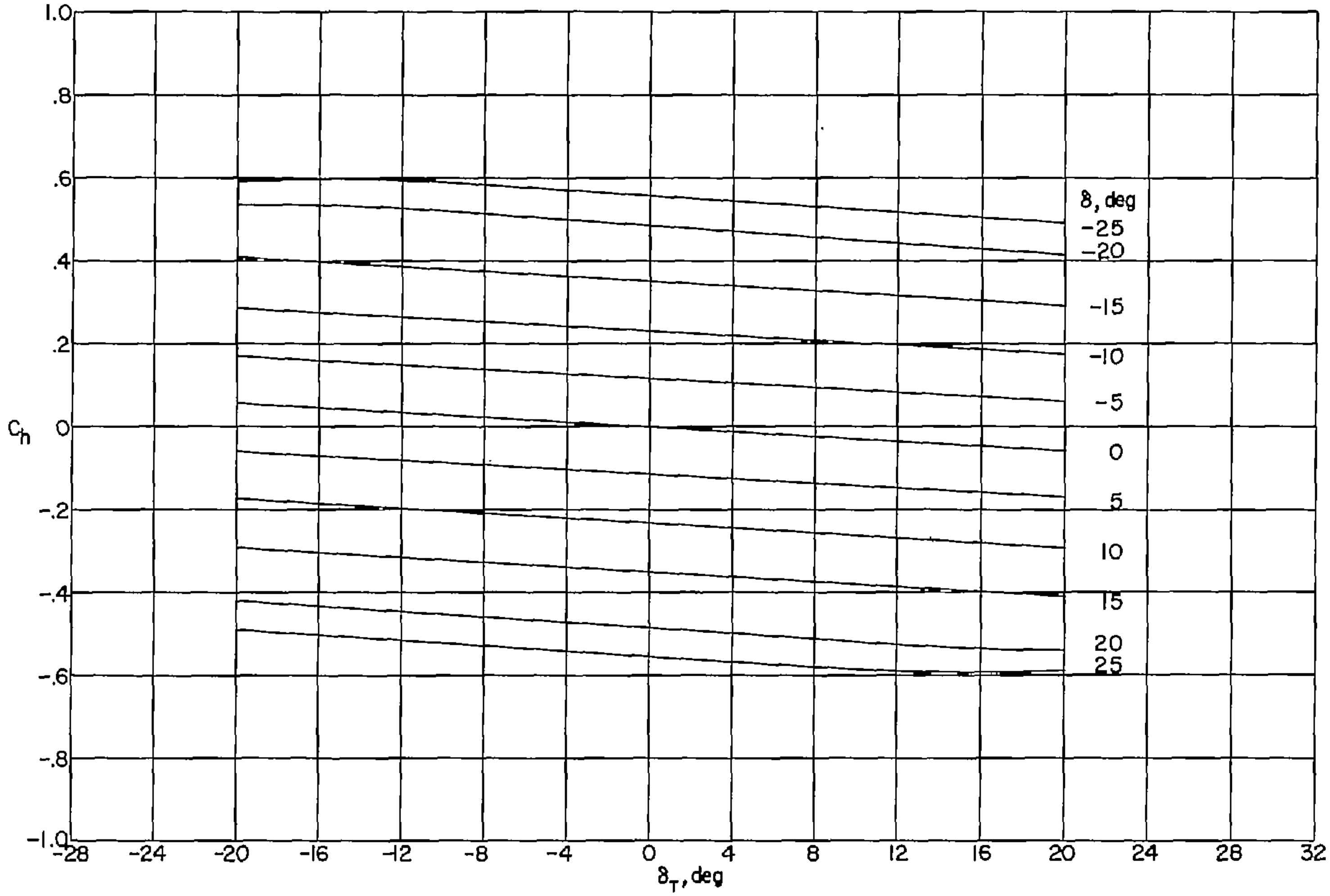
[redacted]



(a) Inboard tab; $\alpha = 0^{\circ}$.

Figure 4.- Variation of control hinge-moment coefficient with tab deflection.

[redacted]



(b) Outboard tab; $\alpha = 0^{\circ}$.

Figure 4.- Concluded.

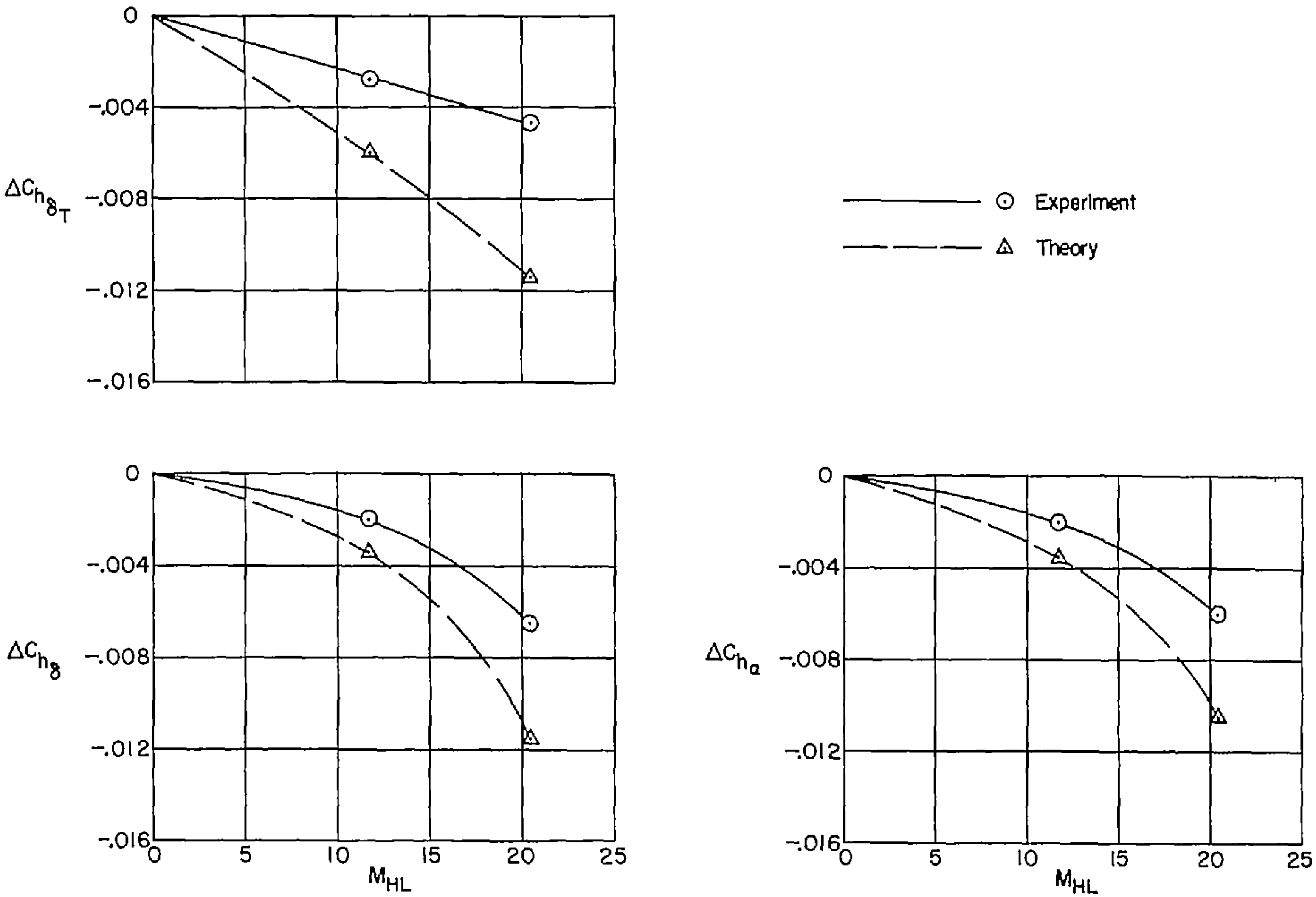


Figure 5.- Variation of the increments in hinge-moment slope parameters with tab-area moment about the control hinge line.

[redacted]

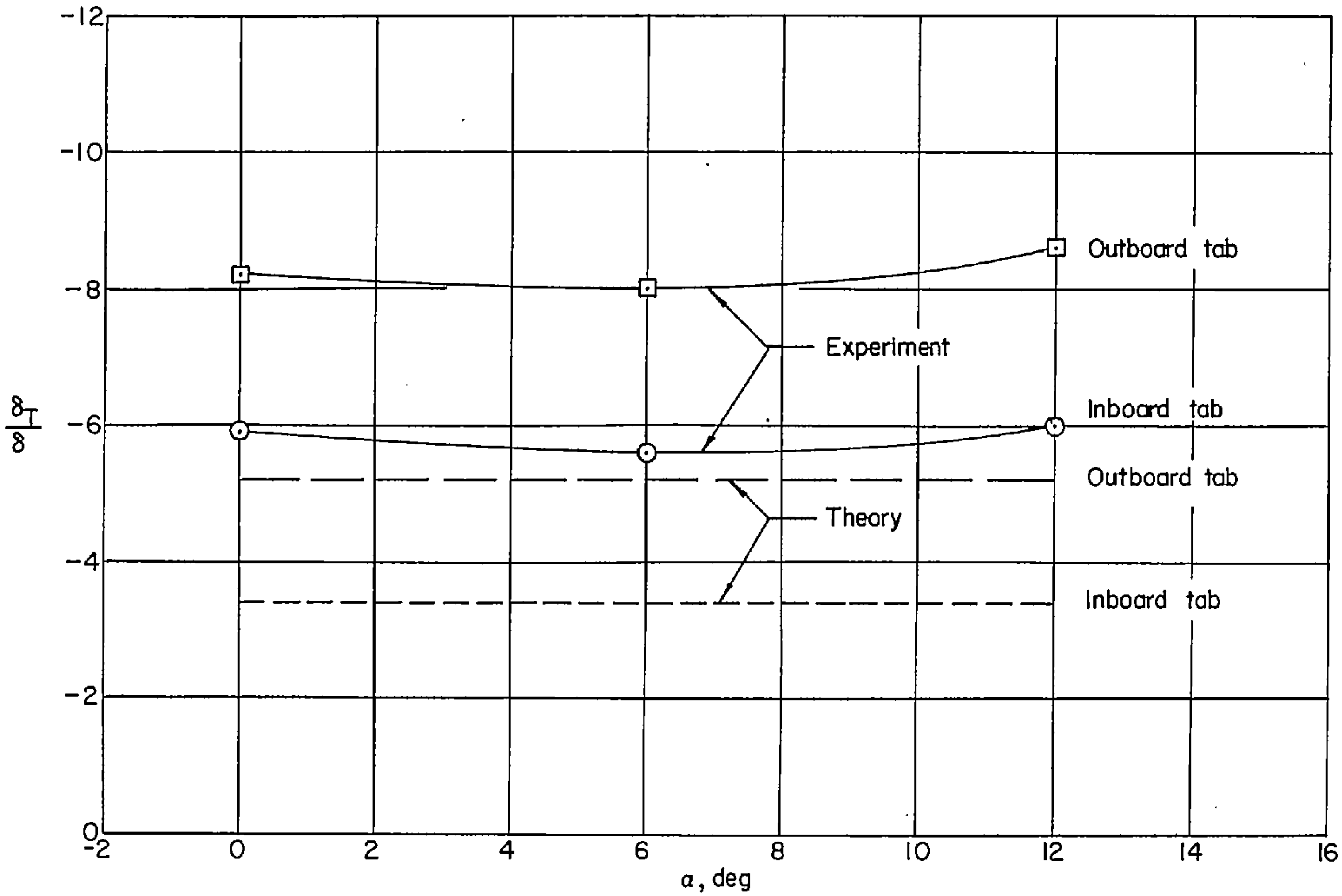


Figure 6.- Variation with angle of attack of the ratio of tab deflection to control deflection required for $C_{h_\delta} = 0$.

[redacted]